Exercise 4.10.1

Note that the vocal cord system takes a constant input and produces a periodic airflow that corresponds to its output signal. Is this system linear or nonlinear? Justify your answer.

Singers modify vocal cord tension to change the pitch to produce the desired musical note. Vocal cord tension is governed by a control input to the musculature; in system's models we represent control inputs as signals coming into the top or bottom of the system. Certainly in the case of speech and in many other cases as well, it is the control input that carries information, impressing it on the system's output. The change of signal structure resulting from varying the control input enables information to be conveyed by the signal, a process generically known as **modulation**. In singing, musicality is largely conveyed by pitch; in western speech, pitch is much less important. A sentence can be read in a monotone fashion without completely destroying the information expressed by the sentence. However, the difference between a statement and a question is frequently expressed by pitch changes. For example, note the sound differences between "Let's go to the park." and "Let's go to the park?";

For some consonants, the vocal cords vibrate just as in vowels. For example, the so-called nasal sounds "n" and "m" have this property. For others, the vocal cords do not produce a periodic output. Going back to mechanism, when consonants such as "f" are produced, the vocal cords are placed under much less tension, which results in turbulent flow. The resulting output airflow is quite erratic, so much so that we describe it as being **noise**. We define noise carefully later when we delve into communication problems.

The vocal cords' periodic output can be well described by the periodic pulse train $\boldsymbol{pT}(\boldsymbol{t})$ as shown in the periodic pulse signal (Figure 4.1), with T denoting the pitch period. The spectrum of this signal (4.9) contains harmonics of the frequency

$$\frac{1}{T}$$

, what is known as the **pitch frequency** or the **fundamental frequency F0**. The primary difference between adult male and female/prepubescent speech is pitch. Before puberty, pitch frequency for normal speech ranges between 150-400 Hz for both males and females. After puberty, the vocal cords of males undergo a physical change, which has the effect of lowering their pitch frequency to the range 80-160 Hz. If we could examine the vocal cord output, we could probably discern whether the speaker was male or female. This diference is also readily apparent in the speech signal itself.

To simplify our speech modeling efort, we shall assume that the pitch period is constant. With this simplifcation, we collapse the vocal-cord-lung system as a simple source that produces the periodic pulse signal (Figure 4.14). The sound pressure signal thus produced enters the mouth behind the tongue, creates acoustic disturbances, and exits primarily through the lips and to some extent through the nose. Speech specialists tend to name the mouth, tongue, teeth, lips, and nasal cavity the vocal tract. The physics governing the sound disturbances produced in the vocal tract and